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The revised distance of supernova remnant G15.4+0.1

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Abstract We measure the distance to the supernova remnant G15.4+0.1 which is likely associated with TeV source HESS J1818–154. We build the neutral hydrogen (HI) absorption and ^{13}CO spectra for supernova remnant G15.4+0.1 by employing data from the Southern Galactic Plane Survey (SGPS) and the HI/OH/Recombination line survey (THOR). The maximum absorption velocity of about 140 km s^{-1} constrains the lower limit of its distance to about 8.0 kpc. Further, the fact that the HI emission feature at about 95 km s^{-1} seems to have no corresponding absorption suggests that G15.4+0.1 likely has an upper limit for distance of about 10.5 kpc. The ^{13}CO spectrum for the remnant supports our measurement. The new distance provides revised parameters on its associated pulsar wind nebula and TeV source.

Key words: ISM: supernova remnants — methods: data analysis — stars: distances

1 INTRODUCTION

The supernova remnant (SNR) G15.4+0.2, also called G15.42+0.18 (G15 hereafter), has a break-out morphology toward its south and a northern shell with a radius of about 6′ in 1420 MHz. The spectral index of G15 is -0.62 ± 0.03 from 330 to 4800 MHz (Supan et al. 2015; Sun et al. 2011) with its peak flux density of 5.6 Jy at 1 GHz. G15 has a morphological correspondence with the TeV γ-ray source HESS J1818–154 (Adrián-Martínez et al. 2011). The high energy radiation possibly originates from a pulsar wind nebula (PWN) although the pulsar has not been detected. Multiwavelength studies have been performed to explore their properties (e.g. H. E. S. S. Collaboration et al. 2014; Castelletti et al. 2013).

Distance is a key to further study this TeV SNR. A near distance for the remnant G15 was suggested by Castelletti et al. (2013) by analyzing a noisy HI absorption spectrum of the remnant. We make a further effort to obtain a reliable distance to it by taking advantage of data from the newly-released HI/OH/Recombination line survey (THOR, Beuther et al. 2016), as well as the archive Southern Galactic Plane Survey (SGPS, McClure-Griffiths et al. 2005), the Very Large Array Galactic Plane Survey (VGPS, Stil et al. 2006) and the Galactic Ring Survey (GRS, Jackson et al. 2006).

The SGPS has a resolution of 100″ and a sensitivity of less than 1 mJy beam^{-1}, and was observed by the Australia Telescope Compact Array (ATCA) and Parkes telescopes. The SGPS survey has a reliable absolute flux scale by including the Parkes data. The continuum data of SGPS near the G15 region are currently not available. The THOR survey observed HI, four OH and 19 H_α recombination lines, and the L-band continuum covering the northern Galactic plane ($15^\circ < l < 67^\circ$ and $|b| < 1^\circ$). The THOR data have an angular resolution of about 20″. We convert the unit of Jy beam^{-1} in the THOR data to Kelvin (K) using factors of 1536.20 for the data cube. The absolute scale of the surface brightness in the THOR data is not reliable due to lacking a zero baseline. However, the relative scale is good enough for us to do HI absorption analysis. In addition, we adopt the ^{13}CO data from the GRS to confirm the reality of the

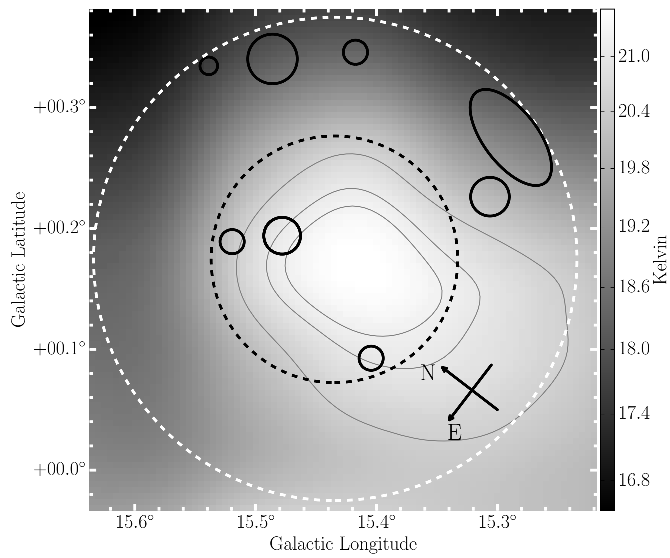

Fig. 1 The image of G15 at 1420 MHz from the VGPS data. The *black dashed circle* shows the source region ('ON' direction) with its center at $(g, l) = (15.43^\circ, 0.17^\circ)$ and a radius of $6.1'$. The region between the *black dashed circle* and the *white dashed circle* is the background region ('OFF' direction). The *black solid circles* show point-like sources from the THOR continuum image, which are excluded from our analysis. The *black solid ellipse* shows a bright source in the SGPS HI channel maps, which is also flagged in our spectral analysis. The gray contour levels are 20.5, 21.0 and 21.2 K.

absorption peaks, because ^{13}CO is a tracer of cold and dense H_2 molecular clouds.

2 SPECTRAL ANALYSIS

We use well-tested methods in order to build as reliable of an HI absorption spectrum for G15 as possible (Tian et al. 2007; Tian & Leahy 2011; Zhu et al. 2013).

We improve how the absorption spectrum is extracted by using two steps. We choose a background region which is an annulus around the source region. Our background is adjacent to the source region, which makes the background spectrum be in the source direction. We remove six point-like sources from both the continuum map and the data cube to avoid contamination (see Fig. 1). We show the HI emission, the HI absorption and the ^{13}CO emission spectra of G15 (see Figs. 2 and 3). We extract the HI emission spectra from our source and background regions and then calculate the difference between the two spectra. This difference spectrum is actually proportional to the absorption spectrum, which is used to do absorption analysis. We extract the ^{13}CO spectrum in our selected background region from the GRS data and compare it with our absorption spectrum.

The HI absorption feature corresponding to maximum velocity appears at about 140 km s^{-1} (see Figs. 2 and 3). The ^{13}CO has data between -5 km s^{-1} and 135 km s^{-1}. There is, in fact, a ^{13}CO emission feature at 135 km s^{-1} which seems to match the HI maximum velocity absorption feature. The rms of 0.009 K is obtained by averaging regions with no ^{13}CO emission-line features in velocity ranges from -5 to 10 km s^{-1} and from 60 to 120 km s^{-1}. The ^{13}CO peak temperature at 135 km s^{-1} is 0.047 K, which is a 5σ detection. This supports the HI absorption feature at about 140 km s^{-1} being real. The velocity of 140 km s^{-1} corresponds to a distance of about 8 kpc based on the Galactic rotation model with $\Theta_\odot$ = 220 km s^{-1} and $R_\odot$ = 8.5 kpc (Fich et al. 1989). Thus, the lower limit for distance of G15 is 8 kpc.

The HI emission at a velocity of about 95 km s^{-1} seems to have no associated absorption, which means G15 is likely located in front of this HI cloud. This velocity corresponds to a far side distance of about 10.5 kpc. The absorption peak at the velocity of about -20 km s^{-1} is possibly caused by HI emission fluctuation, so it is likely not a real feature (see the HI emission spectra in Figs. 2 and 3). A similar fake absorption feature is often seen in faint SNRs (e.g. Leahy & Tian 2008).

3 RESULTS AND BRIEF DISCUSSION

We obtain a new distance of 9.3±1.3 kpc for G15. This is consistent with the 10±3 kpc derived from the surface

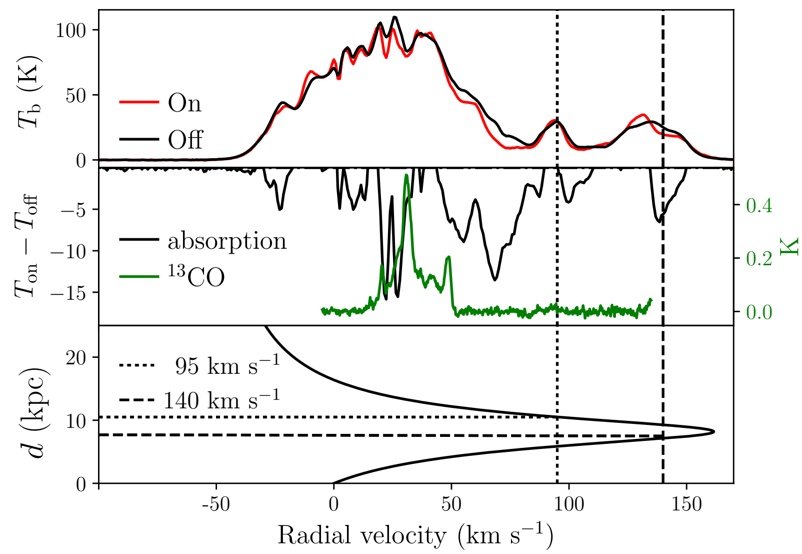

Fig. 2 The HI emission (*top panel*), and HI absorption and ^{13}CO spectra of G15 from SGPS and GRS data (*middle panel*). The *bottom panel* shows the relationship between radial velocity and distance.

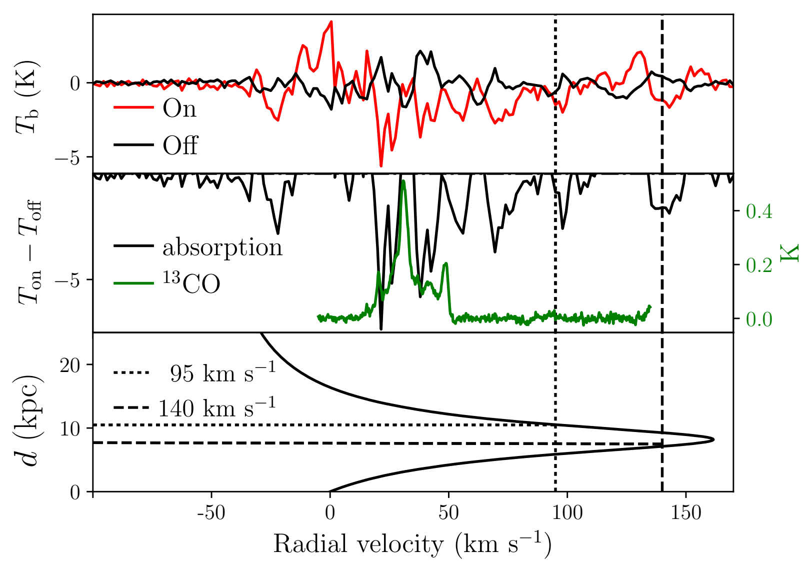

Fig. 3 The HI emission, HI absorption and ^{13}CO spectra of G15 from THOR and GRS data. Panel descriptions are the same as those in Fig. 2.

brightness versus diameter relation of Galactic SNRs (Adrián-Martínez et al. 2011). Castelletti et al. (2013) showed an HI absorption spectrum and suggested a smaller distance for the remnant. However, we do not find a clue from their paper to reproduce their spectrum, so we believe our careful measurement is more reliable.

The HI shell of G15 is 16.5 pc in radius (for 6.1′) at a distance of 9.3 kpc. The PWN inside G15 has a total energy of less than 1.2×10^{50} erg scaled from the value derived in H. E. S. S. Collaboration et al. (2014).

We revise the parameters of G15 using the shell-type model of an SNR in Sturner et al. (1997). We assume the progenitor supernova of G15 has an explosion energy of 10^{51} erg, a mass of 8 $M_{\odot}$, a magnetic field strength of 1 μG and an interstellar medium (ISM) density of 7 hydrogen atoms per cubic centimeter, so we get the expansion velocity of about $700\,\mathrm{km\,s^{-1}}$, an age of 11 kyr and a total atomic gas mass that forms the G15 shell of $3.3 \times 10^3\, M_\odot$. The estimated parameters may have a 50 percent uncertainty due to the large variance in ISM density.

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